Superlattices and Microstructures 91 (2016) 22–30

Contents lists available at ScienceDirect

Superlattices and Microstructures

journal homepage: www.elsevier.com/locate/superlattices

High efficiency quadruple junction solar cells

R. Bestam [a], A. Aissat [a, b, *], J.P. Vilcot [c]

[a] LATSI Laboratory, Faculty of the Technology, University of Blida 1, BP270, 09.000, Algeria
[b] LATSICOM Laboratory, Faculty of Science, University of Blida 1, BP270, 09.000, Algeria
[c] Institut d'Electronique, de Microélectronique et de Nanotechnologie, UMR CNRS 8520, Université des Sciences et Technologies de Lille1, Avenue Poincaré, CS 60069, 59652 Villeneuve d'Ascq, France

ARTICLE INFO

Article history:
Received 14 November 2015
Accepted 24 December 2015
Available online 29 December 2015

Keywords:
Semiconductor
New materials
Nanostructures
Solar cell
Optoelectronics

ABSTRACT

This work focuses on the modeling and optimization of a structure based on InGaP/InGaAs/InGaAsN/Ge for photovoltaic. In this study we took into consideration the concentration effect of alloys x (In) and y (N) on the strain, the bandgap, the absorption and structure efficiency. It has been shown that the concentration of indium varies the strain and the bandgap. These two parameters change considerably the yield. Also it optimized the effect of alloys on the total absorption of the structure. For a concentration of indium x = 0.40 and y = 0.03 we had a absorption coefficient which is equal to 2×10^6 cm^{-1}. We have found 50% efficiency for the multi-junction structure based on $In_{0.55}Ga_{0.45}P/In_{0.40}Ga_{0.60}As/In_{0.30}Ga_{0.70}As_{0.97}N_{0.03}/Ge$. To achieve a reliable high efficiency multi-junction structure, we just need to optimize the concentrations of different alloys.

1. Introduction

The gallium nitride and its ternary and quaternary alloys in the system Ga (B, In,Al) N have become in recent years the headlights semiconductors in optoelectronics field. Indeed, these materials suffer from lack of agreement mesh substrates for epitaxial growth. They have also a high defect density difficult to achieve p-type doping particularly, the gallium nitride and indium takes a considerable place in photovoltaic field since a decade [1]. These alloys have a bandgap that covers the visible spectrum. They are candidates for the realization of multi-junction solar cells with very high efficiency.

The solar cell technology based on triple junction structure GaInP/GaInAs/Ge is performed at 30% conversion efficiency under lighting AM_0 [2].

Metamorphic solar junction cells have been studied for terrestrial solar applications and in space. The modeling of components indicates that performance improvements are possible with the splitting of the spectrum still optimized by the use of the disagreement of mesh of semi-conductors III–V.

However, the terrestrial spectrum conversion efficiency equal to around 40% was considered at the high solar concentration using the triple junction cell [3].

The simple solar cell can absorb a finite interval of wavelength in solar spectrum and thus produce less efficiently.

In contrary, the solar cells multi-junctions absorb the maximum of the solar spectrum. Each junction absorbs a portion of the solar spectrum [4].

* Corresponding author. LATSI Laboratory, Faculty of the Technology, University of Blida 1, BP270, 09.000, Algeria.
E-mail address: sakre23@yahoo.fr (J.P. Vilcot).

http://dx.doi.org/10.1016/j.spmi.2015.12.038
0749-6036/

Multi-junction photovoltaic systems of high-efficiency are formed of III–V semiconductor alloys with a high optical sensitivity. The perfect combination of the band gap energy increases the absorption coefficient of photons. It creates more electron–hole pairs and thus increases the efficiency of the solar cell [4].

Researchers have introduced a new multi-junction photovoltaic cell constituted by GaP/InGaAs/InGaSb structures [4]. Then they compared with simple multi-junction solar cells which already in existence. Several researchers have made the design of solar cells with agreement and disagreement meshes. They tried to reach a theoretical yield of 60% and even more [5,6].

On the other hand, the multi-junction solar cells have evolved to extract energy from a larger energy band of the solar spectrum [7,8].

The multi-junction solar cells can be grouped into two types depends on spectrum splitting up techniques and also the orientation of the intermediate junctions. The two types are, known as vertical multi-junction (VMJ) and as lateral multi-junction (LMJ) [9,10].

Generally, VMJ solar cells are more expensive compared to single junction cells because of costly manufacturing steps due to different materials layers [9].

However, the strain and the faults of interface significantly affect the manufacturing efficiency and performance of VMJ solar cells [11].

For III–V multi-junctions of high quality the recombination is widely radiative. This effect may have a significant effect on the short-circuit voltage (V_{OC}), and photocurrent densities (JCS) of junctions [12–14].

Therefore, there is a significant work in the literature on experimental extraction and modeling luminescent coupling parameters derived from (J_{CS}) [12–14].

Also our modeling purpose is to study different multi-junctions structures of cells based on semi-conductors with significant importance to exceed conversion efficiency of 50%.It is shown that the use of several layers of different materials mounted in vertical increase the performance and reliability of the solar cell.

2. Theoretical model

III–V semi-conductors are known for having a very important optical transition and procedures for manufacturing and growth are currently sufficiently well normalized. The properties of the quaternary alloys ABCD are found by the interpolation of the properties of binary Alloys AB or properties of ternary alloys ABC. The properties of the ternary alloys $A_{1-x}B_xC$ are given by the following relationship:

$$P_{ABC}(x) = x.E_{BC} + (1-x)P_{AC} + x.(1-x)C_{ABC} \tag{1}$$

C_{ABC} is the parameter of Bowing and P represents the parameter of materials. For the calculation of the mesh parameter of the alloys, C_{ABC} is zero [15].

From the formulas of empirical interpolation for the ternary alloys $A_{1-x}B_xC$, the properties of the quaternary alloys $A_xB_{1-x}C_y\ D_{1-y}$ are interpreted by:

$$P(x,y) = \frac{x.(1-x)[y.T_{ABC}(x) + (1-y).T_{ABD}(x)] + y(1-y)[x.T_{ACD}(y) + (1-x).T_{BCD}(y)]}{x.(1-x) + y(1-y)} \tag{2}$$

The approach of eq (2) tends to give better agreement with experiment than an alternative treatment of Moon et al. [16] which is known to overestimate the quaternary bowing [17,18] Krijn [19] gives polynomial expansions of Q(x,y) derived from eq (2) for the energy gaps and spin–orbit splitting of several III–V quaternaries.

The quaternary may then be represented as a combination of two lattice-matched constituents, one of which must be a ternary while the other may be either a binary or a ternary.

The semiconductor materials in the hetero-structures do not necessarily have the same mesh parameters a.

- These internal deformations have important consequences for the electronic and optoelectronic properties, and can be exploited to achieve high performance structures.
- Some semiconductors are not necessarily in agreement to mesh with the available substrates. A solution is to make them grow without agreement of mesh. In this case, the dislocations will be formed and possibly the high layer may be used as 'pseudo-substrate'. This procedure of growth, allows in principle to have an improved flexibility in the technology of semiconductors [20].

To perform the growth of a semiconductor (1) for parameter of mesh a_1 on a semiconductor (2) with a mesh parameter a_2. The strain between the two materials is defined as: